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Factors affecting the success rate of extracorporeal shock wave lithotripsy for renal calculi in children

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Abstract The aim of the study was to analyse factors affecting the success rate of extracorporeal shock wave lithotripsy (ESWL) in children with renal calculi. We performed a retrospective analysis reviewing records of 85 (40 female, 45 male) children (89 renal units) subjected to ESWL for treatment of renal calculi during 1990–2005 in our department. As 4 patients had bilateral calculi and 19 children (21 renal units) had renal stones at more than one different site, each location was analysed separately for convenience. The mean age of the patients was 10.3 ± 4.6 (2–16) years. The stone-free rates for renal pelvis, lower, middle and upper caliceal calculi were 70, 62, 50 and 73%, respectively. A higher rate (33%) of insignificant fragments ($\leq$ 4 mm) was noted for lower pole calculi. Increased stone diameter ($P = 0.0001$) and burden ($P = 0.04$) were found as the most significant factors that adversely affect the stone-free rate for pelvis renalis calculi, whereas an acutely oriented infundibulum and/or a long lower infundibulum ($P = 0.005$) were unfavourable factors for clearance of lower caliceal stones. The stone-free rate in children with multiple calculi was 48%, while 29% of the renal units had retained fragments. ESWL is a good initial option for treatment of most of the renal calculi < 2 cm except in the presence of unfavourable lower caliceal anatomy. Increased stone burden, multiple stones, staghorn calculi, narrow lower infundibulopelvic angle and long lower infundibulum are factors that adversely affect the clearance rate.

Keywords Urolithiasis · Extracorporeal shock wave lithotripsy · Children · Stone clearance · Infundibulopelvic angle

Introduction

Extracorporeal shock wave lithotripsy (ESWL) has become the standard initial treatment for most of the renal and ureteral calculi since its introduction by Chaussy et al. [1]. Although ESWL was considered as a safe and effective treatment in adults, a longer period is needed to check its efficacy and morbidity in children [2–4]. Lottmann et al. [4] confirmed no scar development or significant variation of differential function in infants treated with ESWL as well as the absence of hypertension. The advancement of technology and growing experience in ESWL as well as minimally invasive procedures have led to open surgery becoming the last resort in treatment of urolithiasis. Despite numerous reports and growing experience, guidelines for ESWL in children still have not been fully determined. Here, we present our experience with ESWL in the treatment of paediatric renal calculi and analyse factors that affect the success of treatment.

Materials and methods

We performed a retrospective analysis reviewing records of 85 (40 female, 45 male) children with 89 renal units subjected to ESWL for treatment of renal calculi during 1990–2005 in our department. As 4 patients had bilateral (including the case with staghorn calculi) and 19 children (21 renal units) had renal stones at more than one different site (a pelvis and a caliceal stone usually), each location was analysed separately for convenience. Three children with staghorn (one of them bilateral) renal calculi were also included to the series.

Standard evaluation of the patients before ESWL included renal function tests, urinalysis, urine culture

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and intravenous urogram (IVP). Most patients were referred to our clinic from certain centres for ESWL, and metabolic evaluation for the aetiology of urolithiasis was conducted by the paediatric nephrology unit or by the centres referring the patient. Patients with urinary tract infection were treated before ESWL according to urinary cultures with appropriate antibiotics. Contraindications of ESWL treatment were coagulation disorders, pyelonephritis, obstruction distal to the calculi, non-functioning kidney and hypertension. Antibiotic prophylaxis (starting 24 h before treatment up to 5 days post-ESWL) was given to children having a stone size of >2 cm to prevent urosepsis. In our series a double-J stent was inserted in 10 (11%) renal units due to high stone burden (diameter >2 cm) or previously in open renal surgery for residual calculi (6 patients).

ESWL was performed with a Siemens Lithostar plus device usually under dissociative anaesthesia using ketamine 0.5 mg/kg for most children, although sedation was sufficient for some children older than 14 years of age. All the procedures were carried out under fluoroscopic control mostly in the supine position as an outpatient treatment. The shock wave number and voltage were limited to a maximum of 2,500 shock waves/session and 17.2 kV, respectively, for patients under 12 years of age. This limitation was the policy of our clinic to keep the possible damage of shock-waves on the kidney to the minimum. The stone burden was defined as the stone area that was calculated by multiplying the largest length and width of the individual stones measured from the abdominal plain X-ray. In patients with more than one stone, stone burden was accepted as the sum of the individual stones.

The follow-up after ESWL consisted of plain abdominal X-ray, usually 1–2 weeks after treatment and continued according to disintegration and clearance. Complete stone clearance was accepted as stone-free and confirmed with IVP and/or X-ray + ultrasonography in all patients. Residual fragments ≤ 4 mm were accepted as insignificant. Treatment failure was defined as larger fragments or no fragmentation at all.

The success rates after ESWL were classified according to stone localization, stone diameter and stone burden (Tables 3, 4, 5). An additional analysis was done to determine the impact of lower pole anatomy on clearance of fragments from the lower calices. Patients who were stone-free after ESWL for lower caliceal calculi and patients who had residual insignificant fragments in the lower calices despite sufficient fragmentation were compared for anatomical factors using standard IVP. All measurements were done by the same author (O.T.). Lower pole infundibular length and infundibulum width were measured as described by Elbahnasy et al. [5]. Briefly the infundibulum width was accepted as the narrowest diameter, and length as the distance from most distal point at the bottom of the calyx harbouring the stone to the midpoint of lower lip of renal pelvis (Fig. 1). The lower infundibulopelvic angle (LIPA) was measured using two different methods described previously. The first method was that described by Sampaio et al. [6, 7] based on measuring the angle between vertical pelvis axis and vertical axis of lower infundibulum (Fig. 2). The second method was the one described by Elbahnasy et al. [5]. (Fig. 3). The angle between the ureteropelvic axis and vertical axis of lower infundibulum was accepted as the lower infundibulopelvic angle. Accordingly both methods were compared with respect to stone clearance.

Statistical analysis was done with the SPSS (statistical program for social sciences) program. The groups were compared using Mann–Whitney *U* test or Kruskal Wallis analysis for numerical variables, chi-square test for categorical ones and Spearman correlation test. A two-tailed *P* value of <0.05 was accepted as statistically significant.

Results

The mean age of the patients was 10.3 ± 4.6 (2–16) years. Table 1 shows lateralization and gender of the patients according to stone localization. Most calculi were located at either pelvis renalis or lower calices. Stone size, number of shock waves, session and power applied according to stone localization are given in Table 2. The stone-free rates for renal pelvis, lower, middle and upper caliceal calculi were 70, 62, 50 and 73%, respectively (Table 3). A higher rate (33%) of insignificant fragments was noted for lower pole calculi. For calculi ≤ 1 cm in diameter the failure rates for renal pelvis, lower, middle and upper caliceal calculi were 10, 4, 33 and 14%, respectively (Tables 4, 5). Increased stone diameter (chi-square test, $P = 0.0001$; Spearman's correlation analysis, $\rho = 0.44$, $P = 0.001$) and burden (chi-square test, $P = 0.004$; Spearman's correlation analysis, $\rho = 0.43$ $P = 0.001$) were found to be the most significant factors that adversely affect the stone-free rate for pelvis renalis calculi. However, stone diameter (chi-square test, $P = 0.21$; Spearman's correlation analysis, $\rho = 0.13$, $P = 0.45$) and burden (chi-square test, $P = 0.49$; Spearman's correlation analysis, $\rho = 0.12$, $P = 0.47$) were not significantly related to the success rates after ESWL for lower caliceal calculi.

The stone-free rate in children with multiple calculi was 48%, while 29% of the renal units had retained fragments. Among four renal units with staghorn

Table 1 Lateralization and gender of the patients according to stone localization

(*n*)	Gender (%)		Lateralization (%)	
	Boys	Girls	Right	Left
Pelvis (54)	22 (41)	32 (59)	28 (52)	26 (48)
Lower calyx (39)	28 (72)	11 (28)	22 (56)	17 (44)
Middle calyx (4)	4 (100)	0 (0)	3 (75)	1 (25)
Upper calyx (11)	7 (64)	4 (36)	5 (46)	6 (55)

n number of renal units

Table 2 Mean ± SD and range of stone diameter, stone burden, number of shock waves, kV and sessions according to stone localization

Localization	Stone diameter (cm)	Stone burden (cm^2)	No. of shock waves	Voltage (kV)	Session
Pelvis (*n* = 54)	1.31 ± 0.49 (0.6–2.6)	1.56 ± 1.28 (0.2–6)	2504.4 ± 870.8 (1,000–4,600)	16.6 ± 1.6 (13.6–19)	1.6 ± 0.8
Lower calyx (*n* = 39)	1.06 ± 0.49 (0.4–2)	1 ± 0.77 (0.16–4)	2547.6 ± 620.4 (1,200–3,500)	17.3 ± 1.4 (14.1–19)	1.7 ± 0.8
Middle calyx (*n* = 4)	0.95 ± 0.33 (0.5–1.3)	0.89 ± 0.45 (0.25–1.3)	2500 ± 577.4 (2,000–3,000)	17 ± 2.4 (14.1–19)	1.5 ± 0.6
Upper calyx (*n* = 11)	1.21 ± 0.5 (0.5–2)	1.55 ± 1.3 (0.4–4)	2616.7 ± 832.2 (1,500–4,000)	17 ± 1.5 (14.5–19)	1.7 ± 0.7

n number of renal units

calculi, two (50%) had residual fragments ≤ 4 mm, one (25%) had larger retained fragments in the lower calices and only one (25%) unit was stone-free. Stone-street formation occurred in three renal units. After multiple ESWL sessions the patient with bilateral staghorn calculi was subjected to bilateral ureteroscopy for removal of ureteral calculi.

Four children in this series had anomalous kidneys. One of them was a 14-year-old girl having right malrotated kidney. She had a 22 mm (burden = 2.6 cm^2) renal pelvic stone and a 7 mm (burden = 0.6 cm^2) lower calyceal stone on the right. After two sessions of SWL, she had large residual fragments accumulated at the lower calyx and no additional treatment was offered, as she was asymptomatic. The second child, a 16-year-old male, had complete ureteral duplication on the left side, and a 7 mm (burden = 0.77 cm^2) lower calyceal stone in the same renal unit. After three sessions of SWL, the patient had only a 2 mm residual stone fragment that was considered as insignificant. The third patient was a

Table 3 Success rates according to stone site

Localization	Stone-free (%)	Residual ≤ 4 mm (%)	Failure (%)
Pelvis (*n* = 54)	38 (70)	5 (9)	11 (20)
Lower calyx (*n* = 39)	24 (62)	13 (33)	2 (5)
Middle calyx (*n* = 4)	2 (50)	1 (25)	1 (25)
Upper calyx (*n* = 11)	8 (73)	1 (9)	2 (18)
Staghorn (*n* = 4)	1 (25)	1 (25)	2 (50)

n number of renal units

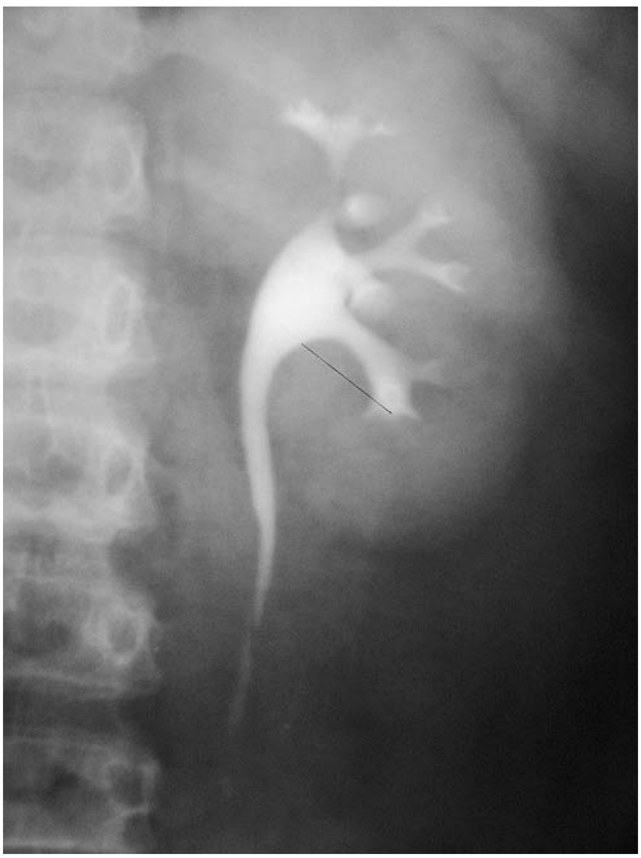

Fig. 1 Lower pole infundibular length measured as the distance from most distal point at the bottom of the calyx harbouring the stone to the midpoint of lower lip of renal pelvis [5]

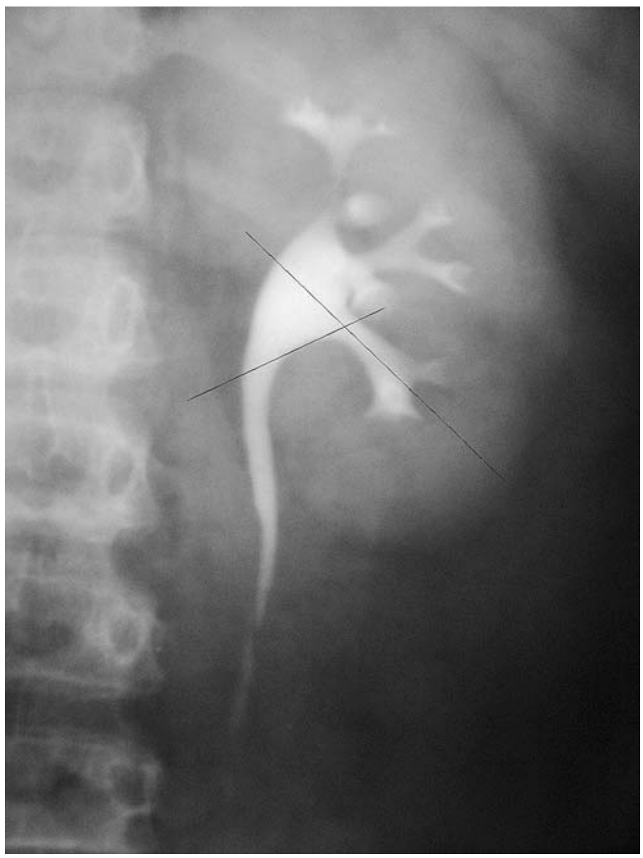

Fig. 2 The lower infundibulopelvic angle (α) measured as described by Sampaio et al. [6, 7] based on measuring the angle between vertical pelvis axis and vertical axis of lower infundibulum

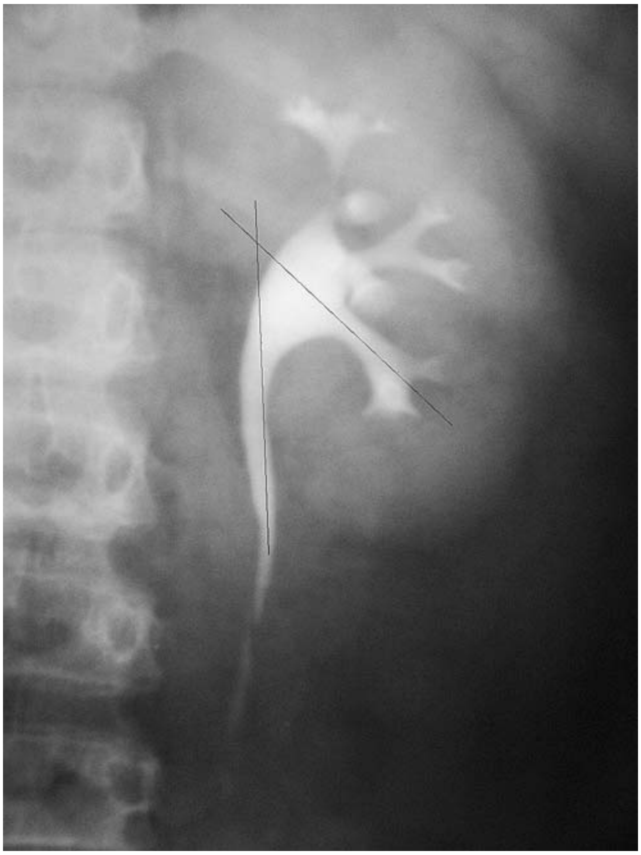

Fig. 3 The lower infundibulopelvic angle (α) measured as described by Elbahnasy et al. [5] A *line* was drawn to connect the central point of pelvis opposite to the margins of superior and inferior sinus and midpoint of the ureter at the level of the end of lower pole to find the ureteropelvic axis. The angle between the ureteropelvic axis and vertical axis of lower infundibulum is accepted as the lower infundibulopelvic angle

15-year-old girl with a left duplicated kidney and a 15 mm (burden 1.5 cm^2) calculus in pelvis renalis of the upper unit completely cleared after one session of SWL. The final patient was a 14-year-old boy with a horseshoe kidney and a 10 mm (burden 1.1 cm^2) right pelvic renal stone who was stone-free after one session.

Finally, patients who were stone-free after ESWL for lower caliceal calculi (24 renal units) and patients who had residual insignificant fragments in the lower calices despite sufficient fragmentation (13 renal units) were compared for anatomical factors using standard IVP. An acutely oriented infundibulum (narrow LIPA) and/or a long lower infundibulum ($P=0.005$) were unfavourable factors for clearance of lower caliceal stones (Table 6).

The overall complications related to ESWL were skin ecchymosis at the site of entry of shock waves in all cases, renal colic that responded to analgesics and emetics in five (6%), stone-street formation in five (6%), need for ureteroscopy in six (7%) renal units. ESWL treatment failures were usually treated with open renal surgery or expectant management depending on the burden and symptoms of the children, as equipment for percutanous surgery was not available on that occasion.

After a mean follow-up period of 31.6 ± 35 (3–120) months, 5 (6%) patients had recurrence from the stone-free state, and the majority of the children with residual fragments were asymptomatic. There was no evidence of growth retardation and any other major complication related to ESWL.

Stone analysis, which was available only in a minority of the patients because of smaller fragments and inability to collect them because of uncooperative parents, was predominantly calcium oxalate. Two patients in this series were found to have cystinuria. Both had previous open renal surgery and had recurrence. One of them had a large pelvis renalis calculus and ESWL was unsuccessful. The patient was offered percutaneous nephrolithotripsy. The other had < 1 cm middle and lower caliceal calculi cleared after ESWL. One patient had parathyroidectomy because of hyperparathyroidism.

Discussion

Extracorporeal shock wave lithotripsy is the treatment of choice for most upper urinary tract calculi in the adult

Table 4 Treatment results related to the stone diameter

Site	≤ 1 cm			> 1 to < 2 cm			≥2 cm			*P* value*
	Stone-free	Res. ≤ 4 mm	Failed	Stone-free	Res. ≤ 4 mm	Failed	Stone-free	Res. ≤ 4 mm	Failed	
Pelvis (*n* = 54)	88% (21/24)	4% (1/24)	8% (2/24)	71% (15/21)	14% (3/21)	14%(3/21)	22% (2/9)	11% (1/9)	67% (6/9)	0.0001
Lower calyx (*n* = 39)	68% (17/25)	28% (7/25)	4% (1/25)	60% (6/10)	30% (3/10)	10% (1/10)	25% (1/4)	75% (3/4)	0% (0)	0.21
Middle calyx (*n* = 4)	67% (2/3)	0% (0)	33% (1/3)	0% (0)	100% (1/1)	0% (0)	0% (0)	0% (0)	0% (0)	–**
Upper calyx (*n* = 11)	67% (4/6)	17% (1/6)	17% (1/6)	100% (3/3)	0% (0)	0% (0)	50% (1/2)	0% (0)	50% (1/2)	–**

n number of renal units
*Chi-square test
**Statistical analysis not performed due to small number of patients

Table 5 Treatment results related to the stone burden

Site	≤ 1 cm^2			> 1 to < 2 cm^2			≥2 cm^2			*P* value*
	Stone-free	Res. ≤ 4 mm	Failed	Stone-free	Res. ≤ 4 mm.	Failed	Stone-free	Res. ≤ 4 mm.	Failed	
Pelvis ($n = 54$)	83% (24/29)	7% (2/29)	10% (3/29)	73% (8/11)	18% (2/11)	9% (1/11)	43% (6/14)	7% (1/14)	50% (7/14)	0.004
Lower calyx ($n = 39$)	65% (15/23)	30% (7/23)	4% (1/23)	64% (7/11)	27% (3/11)	9% (1/11)	40% (2/5)	60% (3/5)	0% (0)	0.49
Middle calyx ($n = 4$)	67% (2/3)	0% (0)	33% (1/3)	0% (0)	100% (1/1)	0% (0)	0% (0)	0% (0)	0% (0)	–**
Upper calyx ($n = 11$)	71% (5/7)	14% (1/7)	14% (1/7)	100% (1/1)	0% (0)	0% (0)	67% (2/3)	0% (0)	33% (1/3)	–**

n number of renal units
*Chi-square test
**Statistical analysis not performed due to small number of patients

population and children. Previous reports have shown similar efficacy for the first- and second-generation lithotripters in children [8]. Short- and long-term studies mostly agree that ESWL is safe with regard to scar formation, renal growth and function; linear growth is not affected and there is no risk of hypertension [3, 4, 9, 10]. Calcium-oxalate monohydrate, struvite, brushite and cystine are more difficult to fragment than uric acid and calcium-oxalate dihydrate stones [11]. Children with a large stone burden might face difficulty in passing stone fragments, urinary obstruction and steinstrasse [9, 12]. In our series a double-J stent was inserted in 10 (11%) renal units due to high stone burden or previous surgery. However, Gofrit et al. [13] has reported that the ability of the pediatric ureter in transporting post-ESWL stone fragments was better than that of the adult as the pediatric ureter might be more elastic and distensible. The authors also noted that the occurrence of stone-street was lower in children. In this series we had a stone-street rate of 5.6% that occurred mostly with staghorn calculi confirming the study by Gofrit et al [13]. Some authors [4, 14] even consider pre-treatment stenting as an adverse factor that might impede stone clearance.

ESWL is a minimally invasive, safe and effective treatment for pediatric urolithiasis. Most series report a stone-free rate of more than 70% (Brinkmann et al. [9], 83%; Nijman et al. [15], 79%; Goel et al. [16], 82%; Elsobky et al. [17], 86%; Netto et al. [18], 98%; Muslumanoglu et al. [19], 73%; Aksoy et al. [20], 87%). Unlike the older reports [2, 8, 15, 16] that give a cumulative stone-free rate, recent data focus on the impact of factors affecting the clearance rate including the location within the kidney [14, 19–23]. Similar to our study, recent reports have concluded that stone size is an important determinant of success after ESWL [19–21]. However, this point is under debate and might depend on stone and patient characteristics. Ather and Noon [14] stated that size does not affect stone clearance in calculi less than 3 cm, while in the series by Muslumanoglu et al. [19] and Elsobky et al. [17] the stone-free rates markedly differed when the stone size exceeded 1 cm for renal pelvis and caliceal stones. The present study, Aksoy et al. [20] and Hasanoglu et al. [21] have reported a marked decrease in clearance rates for pelvis renalis stones greater than 2 cm in diameter. However, we know the excellent results given by Lottmann et al. [24] (82.6% stone-free rate) and Al Busaidy et al. [12] (79% stone-free rate) concerning ESWL monotherapy in children with staghorn calculi. The major consensus might be that infants represent a different population than adults and older children with respect to stone composition and clearance. The series with a high mean age (like the present study) might reflect results similar to those in adults. Thus, our success rate for calculi with higher stone burden is lower than expected. In our study increased stone diameter and burden were found as the most significant factors that adversely affect the stone-free rate for pelvis renalis calculi. Similar to older studies [17, 19] we noted a lower clearance rate for multiple calculi.

Our stone-free rate for paediatric lower pole calculi was 62%, which is similar to adult series, usually reported at between 50 and 60% [5, 25, 26] representing

Table 6 Analysis of factors considered to be related to lower pole stone clearance

Variable	Stone-free ($n = 24$) (mean ± SD)	Residual ($n = 13$) (mean ± SD)	*P* value (M–W *U* test)
Stone diameter (cm)	0.98 ± 0.42	1.21 ± 0.58	0.35
Stone burden (cm^2)	0.89 ± 0.59	1.22 ± 1	0.37
LI-length (mm)	23.2 ± 5.7	34.4 ± 11.2	0.005*
LI-diameter (mm)	5.2 ± 2.1	4.1 ± 1.3	0.16
IPA-pelvic axis (°)	97.1 ± 21	58.3 ± 17.1	0.0001*
IPA-ureteropelvic axis (°)	46.8 ± 7.6	30 ± 7.1	0.0001*

n number of renal units, *IPA* infundibulopelvic angle, *LI* lower infundibulum, *M–W* Mann–Whitney
*$P < 0.05$

a comparatively decreased clearance rate for lower caliceal calculi. Our results were confirmed in paediatric patients by Muslumanoglu et al. [19] with a 50% stone-free rate for lower caliceal calculi (compared to a stone-free rate of 71% for upper, 75% for mid-caliceal and 73% for pelvis renalis calculi) but not by Aksoy et al. [20] (the stone-free rates for pelvis renalis; upper, middle and lower caliceal calculi were 90, 92, 92 and 88%, respectively) and Elsobky et al. [17] (the stone-free rates for pelvis renalis and lower caliceal calculi were 89 and 87%, respectively). The decreased stone clearance for lower pole calculi after ESWL has led to investigations in adults to determine the possible factors for making the patient stone-free [5–7, 26]. An acute LIPA, complex calyceal pattern, anatomical abnormalities, a narrow infundibulum diameter and a long infundibulum are generally accepted as the most adverse prognostic factors for stone clearance [5–7, 26]. Recent studies have raised some debate about the impact of renal anatomy on prediction of stone clearance and reproducibility of the parameters [27, 28]. Similar to adults, debate continues for factors affecting clearance of fragments from the lower calices in paediatric patients [14, 22, 23]. The initial report by Ozgur Tan et al. [22] found that LIPA and lower infundibulum length were significantly different between children who were stone-free and those who had residual fragments. However, in a series with a similar number of patients and a similar burden (median 0.7 cm^2) Onal et al. [23] have suggested that lower pole anatomy and burden do not affect stone clearance in children. Remarkably the authors have an unexplained stone-free rate of 61% (confirming a lower success rate for lower caliceal calculi) which is close to our adult series and their median age was 10.5 years. In a series of 21 children with renal stones ≥20 mm, Ather et al. [29] concluded that lower pole calculi and staghorn calculi extending to lower calices of this size should be preferably treated by a percutaneous approach rather than ESWL. In the present series an acutely oriented infundibulum (narrow LIPA) and/or a long lower infundibulum ($P = 0.005$) were unfavourable factors for clearance of lower caliceal stones. However, stone burden and diameter were not found to be a significantly important factor for clearance of fragments. This result could be attributed to a selection bias, as most of the children with lower caliceal calculi in our series had a stone diameter ≤ 2 cm; thus, with increasing diameter/burden (> 2 cm) clearance might be affected.

In children, treatment of underlying metabolic abnormalities is of the utmost importance for prevention of regrowth and recurrence. Nijman et al. [15] reported an increase in size in 33% and a recurrence rate of 10% in the long term for patients with retained stone fragments. Recently Afshar et al. [30] have pointed out that residual fragments could cause symptoms or increased stone burden in 69% of children. Thus, prediction of stone clearance in children is essential to render the patient stone-free.

The safety and efficacy of percutaneous nephrolithotripsy in children still has not been established completely. Recent studies support minimal or no scar formation and insignificant or no loss of renal function with high stone-free rates [31, 32]. ESWL is surely less invasive than percutaneous nephrolitotomy in children. In previous reports, the nephrostomy tract was dilated up to 21–24F which is rather huge for the paediatric kidney [33]. However, with the advent of technology and introduction of delicate instruments percutaneous nephrolithotripsy might become an effective endoscopic alternative that might be preferred as an initial treatment in children particularly with high stone burden, lower caliceal calculi with unfavourable anatomy, cystine stones, multiple calculi, staghorn calculi and coexisting obstruction [32].

In conclusion ESWL is a good initial option for treatment of most renal calculi < 2 cm except in the presence of unfavourable lower caliceal anatomy. However, multiple factors are involved in stone clearance. Increased stone burden, multiple stones, staghorn calculi, narrow lower infundibulopelvic angle and a long lower infundibulum are the proposed factors that adversely affect the clearance rate.

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